Catchment Hydrological and Biogeochemical Processes in a Changing Environment

draft for final report of FRIEND for phase IV

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This FRIEND group has joined people whose work was connected with small research catchments. Hydrological research in small catchments comprises many aspects of hydrological cycle and naturally results in a variety of research interests. The complex interactions between hydrology, chemistry and ecology have ensured that process studies remain a vital element of catchment studies. A greater understanding and synthesis of the processes and mechanisms responsible for streamflow generation, variation in flow components and cycling of the main nutrients in different physiographic and climatic conditions is needed.

During current FRIEND phase, first, the knowledge gained in experimental research has been used to validate and improve mathematical modelling of hydrological processes (Gűntner et al., 1999, Warmerdam et al., 1999, Koivusalo et al., 2000,). Second, cycling of nutrients and transport of solutes (Andersson & Lepistő, 1998, Peschke & Seidler, 2000, Sambale et al., 2000) has been studied and, third, the changes in hydrological regime due to land use and climate changes have been estimated in small catchments (Buchtele et al., 1998, Querner et al., 2000,).

FRIEND provided a valuable framework for exchanging experience among participants. Because the research interests of group participants were close to interests of the European Network of Experimental and Representative Basins (ERB) community, the last regular ERB conferences were and are to be organized jointly with active participation of group members (Liblice, Czech Republic, 1998, Gent, Belgium, 2000, Demanovská dolina, Slovakia, 2002). Proceedings of the international ERB-NE FRIEND Project 5 workshop organized during the last FRIEND phase in St. Petersburg, Russia, were published during current FRIEND phase (Herrmann, 1999).

Tracer Aided Catchment model, TAC

As it was mentioned above, a variety of hydrological processes can be studied in small catchments. Nevertheless, a lot of research finally results in rainfall-runoff modelling. Despite the knowledge on runoff generation gained in small catchments during the last decades, there are still gaps in the development of rainfall-runoff models that would be based on this knowledge. As an example of application of the knowledge of runoff generation in development of a rainfall-runoff model, the conceptual TAC - tracer aided catchment model (Uhlenbrook & Leibundgut, 1999) can be mentioned. Model development comprised several steps:

a) distribution of the catchment into zones with the same dominating runoff generation processes
b) development of the runoff generation module taking into account the dominating runoff generation process

Spatial delineation of zones with the same dominating runoff generation processes (Rutenberg et al., 1999) was based on the digital terrain model, geological map, forest habitat map and map of saturated areas. Eight spatial units were defined including saturated areas, urban areas, moraines, boulder trains, flat areas, hilltop areas and gently sloping hilly uplands, steeper hillslopes and, boulders on top of steeper units.
Runoff generation module was based on linear and non-linear reservoirs. It distinguished seven zones with characteristic dominating runoff generation process based upon the above mentioned spatial delineation and results of tracer studies. Such a way, different runoff components were calculated. All runoff components from the different reservoirs were added together to give the total catchment simulated discharge.

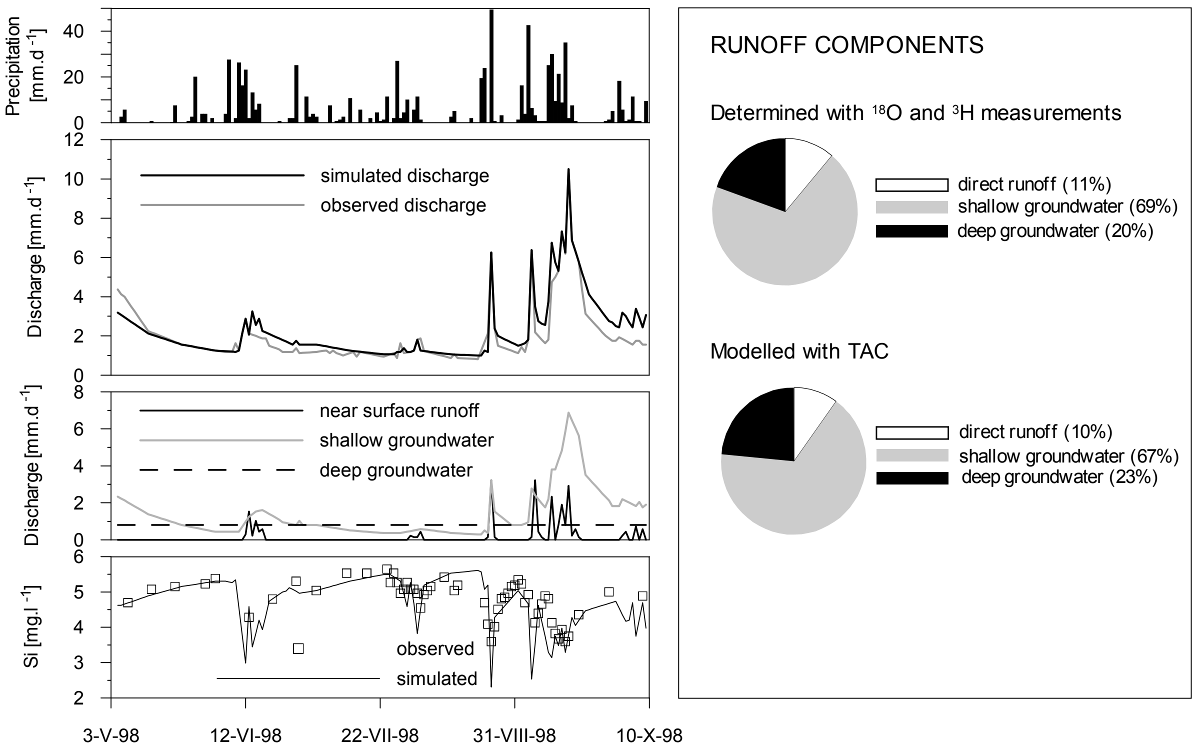

Figure 1 *Example of TAC simulation during validation period (left) and comparison of modelled and tracers-calculated runoff components (right); adopted from Uhlenbrook & Leibundgut, 2001.*

A good agreement was achieved between simulated and observed discharge for the period July 1995-March 1997. The modelled contribution of fast, delayed and slow runoff components corresponded to the results given by ^{18}O measurements (Fig. 1). In addition, the simulated and measured silica concentrations were compared. For the whole investigated period the correlation coefficient (r^2) amounted to 0.36, but for shorter periods a reasonable agreement could be found as shown in Fig. 1. Model simulations appear plausible, as not only the total discharge was simulated reasonably well, but also the modelled proportions of the runoff components were correct (multiple response validation).
The TAC model is a promising example of an approach in rainfall-runoff modelling considering the results of field studies. Improved representation of response of different catchment units to rainfall in a way that enables practical application of the model is important for the study of hydrochemical problems, but may contribute to the simulation of floods and better justified assessment of climate and land use impacts as well.

Hydrological effects of forestry treatment

A lot of experimental catchments is situated in forested areas. Forestry treatment is a major human land use change activity in such areas. Seuna (1999) in a summative paper described the effects of forestry treatments in Finland, namely forest harvesting and draining.

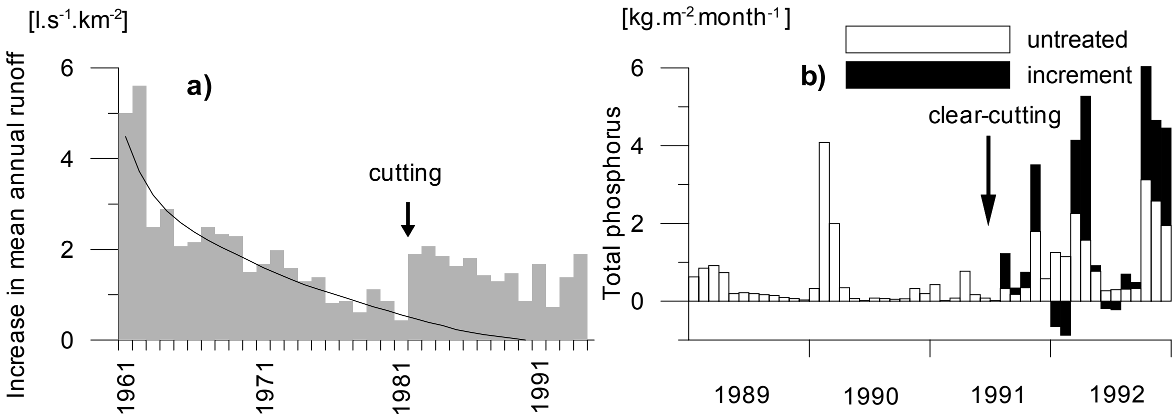

Figure 2 *a) The long-term influence of forestry draining (40% of catchment area) on annual runoff in the Huhtisuonoja catchment; the effect of cutting is also evident; b) influence of clear-cutting (80% of the area) on monthly loads of total phosphorus in the Yli-Knuutila catchment; modified from Seuna, 1999.*

Forestry drainages have been carried out on about 20% of the land area of Finland. It was found that draining has two major effects – decrease of groundwater levels and change of hydraulic properties of the basin. These effects cause depletion of groundwater storage, decrease of evaporation from the soil surface, increase of the water storing capacity of peaty soils and change in transpiration. As a result, the runoff increases. Generally, total runoff increased by 0.3-0.6% per one drainage percent during the first 10 years. This increase was higher during the first years after the drainage and from very wet areas and lower after 10 years, from dry areas or if the drainage percentage was above 50%. After 15-20 years the total runoff returned to its original level. Drainage mostly increased also snowmelt and summer runoff maxima, clearly increased minimum runoff and sediment transport. Forest harvesting (cutting of trees) increased total runoff by 5-10 mm per 10 m^3 timber/ha removed. Spring (snowmelt) maximum increased by 0.5-0.8% per 1% of clearcut area, summer maximum increased by 0.3-1% per 1% of clearcut area. Summer minimum increased strongly but only for a short period. Suspended solids increased by 0.4-1% per 1% of clearcut area but generally remained low. Phosphorus loads increased strongly after forest harvesting, especially from peaty soils. Nitrogen loads also increased but much less and probably for shorter period. Groundwater tables increased after forest removal.

It is important that both treatments, forestry drainage and clear-cutting tend do have parallel effects on hydrological conditions. Application of both treatments in the same area would therefore increase the flooding and erosion risks.

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Future research plans

It is regarded important to maintain and further develop close links between the field workers, physical hydrologists and mathematical modellers. Increasing knowledge on hydrological processes in research catchments using isotope tracers should be reflected in improved mathematical models, e.g. either physically based models with reasonable amount of parameters or conceptual models with new routines describing hydrological processes. Determination of proper parametrization schemes of mathematical models for different scales is an important part of mathematical modelling and should be addressed as well.
A lot of knowledge on runoff generation has already been gained in research, but increasing attempts to synthetize the knowledge, incorporate it into the models and identify the directions of further research will be needed in future. Organization of workshops during group meetings and joint ERB-FRIEND conferences would enhance these attempts.

Related publications by group members

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List of meetings since the third FRIEND Conference at Postojna, Slovenia, held in October 1997

- Prague, Czech Republic, September 25, 1998
- Prague, Czech Republic, June 26, 1999
- Gent, Belgium, September 26, 2000
- Cracow, Poland, September 21-22, 2001